# ANALYSIS OF UNIFORM AND DISCRIMINATORY PRICE AUCTIONS IN RESTRUCTURED ELECTRICITY MARKETS*

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## Abstract

The settlement rule used to determine payments in electricity market auctions can have a profound impact on the amount paid for a particular service. This paper evaluates two auction settlement rules: the uniform price auction in which the last offer accepted determines the price paid to all participants and the discriminatory price auction in which each participant is paid the amount bid by that party. Using an electricity market simulation tool to model the markets for energy and various ancillary services in a large control area, it is demonstrated that under conditions of market power substantial revenues with commensurately high profits can be commanded under a uniform price auction. By employing a discriminatory price rule, much of the impact of market power can be ameliorated. In addition, a discriminatory price auction, by virtue of requiring each bidder to explicitly state their desired revenue rate, provides greater visibility of attempts to make use of strategic pricing and market power. By discouraging the use of market power through greater price visibility, discriminatory price auctions also have the potential to reduce instances of strategic capacity withholding, which in turn, should enhance overall system reliability.

## 1. Introduction

Nearly twenty-five years ago, the movement to increase competition in electricity supply began on a large scale with the Public Utility Regulatory Policies Act of 1978. The Act required regulated utility companies to purchase non-utility generation from "qualifying facilities" at the utility's marginal cost. Later regulations, including the Energy Policy Act of 1992 and FERC Orders 888 and 889 in 1996, gave independent generators greater access to the bulk transmission system. Complementing the Federal activities, a number of states, notably California and many of the Northeastern states, have exercised their regulatory authority to open the electricity generation function to market-based competition.

The results thus far of market-based pricing for wholesale generation have been somewhat mixed. A frequent problem in the wholesale marketplace has been price spikes that occur, generally, when the system is under demand stress. Demand stress can be

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caused by a number of independent, yet potentially coincident, factors including local and regional weather conditions (i.e., high temperatures or storms), unplanned generation outages, transmission flow limitations, and market-related generation shortages. The first three factors relate to the physical attributes of the system (e.g., ambient temperature and humidity, equipment failure, current/temperature limits). The latter factor, also referred to as capacity withholding, is a strategic creation of the marketplace designed to force market price, and therefore revenues, higher. This type of action is labeled by some as "gaming" the system, but in a pure competitive business environment, it is but a strategy to maximize profit. [It is important to recognize that for generation suppliers the "obligation to serve" went out with the elimination of territorial monopoly.]

The purpose of this research is to investigate market mechanisms that can improve electric reliability and also reduce cost to the consumer. This paper describes the analysis of a commonly used pricing mechanism that, in the opinion of the author, encourages the exercise of market power, with its subsequent detrimental impacts on reliability and cost. An alternative pricing approach is quantitatively evaluated as to its potential to reduce the impact of bidding practices that are driven by market power.

## 2. Hypothesis

The trading of electricity in today's open marketplace is coordinated by an entity that seeks to match buyers (i.e., loads) and sellers (i.e., generators). The entity may take the form of a power exchange, as in California, and/or an Independent System Operator (ISO), as found in many states. In addition to serving as matchmaker for electrical energy consumers and suppliers, the ISO must also ensure that the overall grid system remains stable, responsive, and reliable in the face of unexpected events such as an immediate plant outage (trip). To do so requires the commitment of generation assets that must stand ready to react to system changes. These activities, referred to as ancillary services[1], have been defined such that they, too, can be procured in a competitive market environment. Thus, suppliers have multiple, interdependent markets in which they can choose to participate. In its simplest form, an auction is conducted for energy and each ancillary service in which suppliers offer an amount of capacity for a given period of time for a particular price (i.e., the bid price). The coordination entity (e.g., ISO) selects winning offers on the basis of rank-ordered bid price until the projected demand is met.

The current commonly-used settlement rule is to pay ***all*** winning participants at a rate equal to the last (i.e., highest) accepted bid price, irrespective of the participant's own bid price. This approach is referred to as a uniform price auction and is well documented in economic literature (e.g., Feldman 1993). It is not clear, however, why this settlement

[1] The Federal Energy Regulatory Commission (FERC) has defined ancillary services as those "necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system." Ancillary services include regulation (maintaining minute-to-minute generation/load balancing), spinning reserve (capacity that is synchronized to the grid that can respond immediately to grid disturbances), and non-spinning reserve (capacity not connected to the system but capable of being brought on-line and serving demand in a short timeframe (e.g., 10 minutes)).

rule has become the one most often applied to multiunit, multidimensional markets for electricity. A number of researchers have begun to question the use of uniform price settlements in these markets and to suggest that there are other settlement rules that can produce a more efficient and cost-effective outcome (Mount 1999, Oren 2000). The rule proposed by Mount (1999) and evaluated in this paper is the discriminatory price auction. Under this method, the selection process is the same as described above but, in this case, the winning participants are paid exactly what each bid. This method has also been called the pay-as-bid approach.

Mount (1999) provides a good theoretical basis for using a discriminatory price auction in electricity markets. The analysis that follows seeks to evaluate the quantitative benefits to the consumer of using such a pay-as-bid approach as compared to the uniform price approach for settlement of energy and ancillary service markets within a stereotypic, large transmission control area.

## 3. Analysis Tool

In order to understand the economic impacts of alternative market mechanisms in the scheduling and procurement of electric energy, a means of simulating the behavior of markets under various rules and conditions is needed. As part of Oak Ridge National Laboratory's collaboration with the Consortium for Electric Reliability Technology Solutions (CERTS), a multi-generator, multi-hour simulation model has been developed to facilitate analysis of various market arrangements. The ORNL Electricity Market Model (OREMM) serves as a tool to better understand, test, and predict the resulting prices, participation in, profits, and coverage of the interrelated, competitive electric energy and ancillary services markets. The pc-based simulation model has been designed with the following attributes:

- Capable of multiple, diverse generation units and fuel types
- Sequential hourly analysis of energy and individual ancillary service demands
- User-provided bids for energy and ancillary services by unit
- Tracking of sales, actual cost, and profit by unit
- Capable of modeling different market rules and behaviors.

The model simulates the auction process in which hourly energy demand is satisfied by bid-ordered generation. After an initial energy assignment has been made, the various ancillary services are considered in order of their required response time (i.e., regulation, then, spinning reserve, load following[2], and non-spinning reserve). Each of these services is limited by the user-defined quantity available and unit ramp rate considerations. In a similar manner to the energy assignments, each ancillary demand is matched to generation resources, ranked by bid price.

[2] Although not universally defined as an ancillary service, load following is included in the model to reflect the capacity margins that must be available for intra-hour load changes.

For each market, the model calculates the amount paid to each unit, the unit's internal variable cost (based on heat rate, fuel cost, and other variable operating costs), and the resulting profit from the transaction. These amounts are summed across all units to obtain a total-market payment, cost, and profit for each service.

## 4. Example Scenario

In order to obtain cost results with realistic orders of magnitude, the ORNL Electricity Market Model was used to simulate a large transmission control area having a peak annual energy demand of 50,000 MW. The generating units available to meet the load were modeled after plants located in the PJM control area. Recent actual plant data served as a guide in developing model inputs. While similar in size and composition to the PJM market, this analysis and associated simulations are not intended to portray the PJM area specifically, but rather the simulations are meant to provide results that are representative in behavior and magnitude to large, multi-plant control areas having a broad mix of generation types.

As mentioned earlier, aberrant price behavior occurs frequently when a system experiences high demand. For this analysis, a peak hour was simulated in which the system load factor was 94%. In addition to an energy demand of 48,700 MW, ancillary service demands included 500 MW of regulation, 1150 MW of spinning reserve, 1000 MW of load following, and 500 MW of non-spinning reserve. Bids for each plant were based on the expected marginal (clearing) price for that hour. In practice, suppliers do not know with absolute certainty what the total demand for a given hour will be. Certainly, historical data coupled with weather predictions can obtain fairly accurate estimates, however. Similarly, bidders cannot predict with certainty the last accepted bid price, so bidders would likely bid their expectation of the marginal price or perhaps slightly less to improve their selection chance.[3] For the given hourly load in this study, the expected marginal price was assumed to be between $200 and $250 per MWh with bids varying accordingly. For the few plants whose production cost was greater than $200/MWh (e.g., small oil-fired internal combustion units), the energy bid for that plant was set to its production cost. Ancillary service bids were related to the energy bid, adjusted upward by 5 to 15 percent to recognize the incremental cost impacts of varying (and/or lower) output operation.

If this were all that was done to produce plant bids, the economic impact of uniform and discriminatory price auctions on the consumer would not differ greatly. Thus far, bids have been based on the assumption that the bid price for the marginal unit will be based on its costs with, at most, some allowance for a fair profit. In a highly competitive marketplace with many potential suppliers, this is not an unreasonable assumption. However, what has been experienced on occasion in actual markets is an exercise of

[3] Under uniform price auctions, bidders are not compelled to bid the expected marginal cost, as only one plant will determine the payment value for all successful bidders. As a result, zero price bids have been observed in uniform price auctions in order to guarantee selection. In a discriminatory price auction, each bidder must submit a more carefully considered bid, as the revenue obtained will be directly related to the bid amount.

market power in which inadequate supply has caused exorbitant prices to be bid under the logic of charging what the market will/must bear. Whether the shortage is due to true resource shortfalls or intentional supplier withholding, the result is a situation in which suppliers can, during that period, be the tail that wags the dog. It is in these circumstances that discriminatory price rules can protect the consumer by limiting the windfall profits that accrue to participating suppliers under uniform price rules.

To quantify the effect of these rules, it was assumed for the simulation that market power was exercised in the spinning and non-spinning reserve markets. In these markets, a few bidders (including the marginal bidder) chose to offer reserve at fifty times their plant's normal production cost, resulting in bid prices greater than $1000/MWh. In comparing the impact of the two settlement rules, identical input data (e.g., bids, loads, plant parameters) were used.

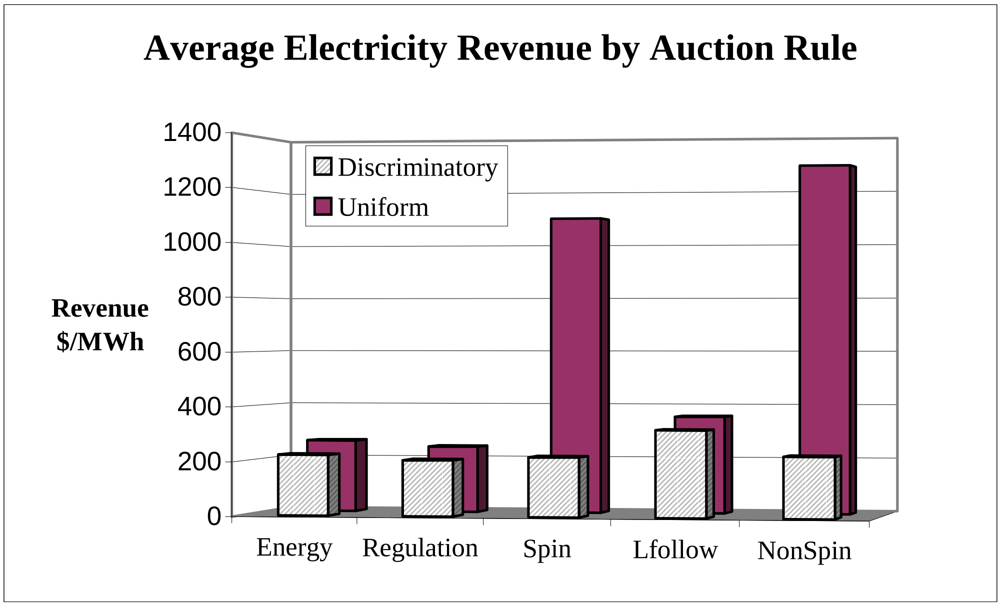
## 5. Scenario Results

For each electricity service (i.e., energy, regulation, spin), the Electricity Market Model determined the degree of utilization, cost, revenue, and profit individually for each plant submitting a bid. A listing of the outcome for each plant is too lengthy for this paper; however, a summary of the results under both uniform pricing and discriminatory pricing rules is provided in the table below.

| Service | Demand (MW) | Average Revenue ($/MWh) | Average Cost ($/MWh) | Average Profit ($/MWh) |
|---|---|---|---|---|
| **Uniform Pricing Rule** | | | | |
| Energy | 48,700 | 265 | 23 | 242 |
| Regulation | 500 | 243 | 5 | 238 |
| Spin | 1,150 | 1,095 | 0[4] | 1,095 |
| Load follow | 1,000 | 358 | 16 | 342 |
| Non-spin | 500 | 1,288 | 0 | 1,288 |
| **Discriminatory Pricing Rule** | | | | |
| Energy | 48,700 | 223 | 23 | 200 |
| Regulation | 500 | 205 | 5 | 200 |
| Spin | 1,150 | 218 | 0 | 218 |
| Load follow | 1,000 | 318 | 16 | 302 |
| Non-spin | 500 | 224 | 0 | 224 |
| **Difference (Uniform – Discriminatory)** | | | | |
| Energy | 0 | 42 | 0 | 42 |
| Regulation | 0 | 38 | 0 | 38 |
| Spin | 0 | 877 | 0 | 877 |
| Load follow | 0 | 40 | 0 | 40 |
| Non-spin | 0 | 1,064 | 0 | 1,064 |

[4] Cost to the bidder of providing spinning and non-spinning reserve is less than $0.5/MWh and is shown in the table as zero.

Of particular interest are the results for the spin and non-spin services, where market power has been exercised. Both revenue and related profits received under a uniform pricing rule, in which the last accepted offer sets the price, are considerably higher than for the discriminatory pricing rule, in which each plant receives its bid price. This is shown graphically in the following figure for average revenue by market service. A graph of average profits would be nearly identical.




## 6. Conclusions

The simulation of the energy and ancillary service markets of a large transmission control area indicates that under periods of high demand, where there are few surplus units, market power can be strategically used to increase sellers' revenue and profits. Using an electricity market simulation model to compare market settlement rules, it is observed that the uniform price auction allows market power in the form of limited competitive bids to greatly influence the entire market. A discriminatory price auction limits the impact of such market power by not applying the marginal price to all inframarginal units. In addition, by requiring the submission of individual "to-be-paid" bids, a discriminatory price auction permits greater scrutiny of bidding behavior. By discouraging the use of market power through greater price visibility, discriminatory price auctions also have the potential to reduce instances of strategic capacity withholding, which in turn, should enhance overall system reliability.

Research literature suggests that the use of market power in uniform price auctions, such as depicted in this analysis, is quite likely in a shallow market environment (i.e., high demand, low supply). In his seminal work on market auctions, Smith (1967) proposed that in shallow market conditions bid values and related revenues would be higher in uniform price auctions than in discriminatory auctions. Subsequent research appears to confirm Smith's findings (Wilson 1979, Back and Zender, 1993, Wolfram 1998). Wolfram (1998) suggests that the incentives for high-priced, strategic bids "would not exist if the electricity auction were discriminatory." DOE (2000) states that a recent analysis by Wolak (2000) indicates that exercise of market power in California during the summers of 1998 and 1999 resulted in more than $800 million in payments above competitive levels to generators. More recently, the uniform price method has garnered the attention of the broader media as a cause of high electricity prices in the Northeast (Smith 2000). As consumers endure another summer of tenuous reliability and high electricity prices, perhaps it is time to consider a change in the rules of the game.

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